[PS]Effect of Subcritical Crack Initiation on Hydraulic Fracture*

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Abstract

The challenge of a significant percentage of failed stages in multistage fracture stimulation of unconventional reservoirs is currently common among the operators across the Gulf region of the Middle East. The majority of these failures are caused by the inability to break down the rock subjected to high in-situ stresses with strong tectonic component. In addition to that, within the fractured stages, there are clusters that do not contribute to production. In our presentation, we discuss an alternative fracturing mechanism which can help addressing those two issues. Namely, we bring the laboratory evidences of the delayed initiation of hydraulic fractures under subcritical pressures, that at wellbore pressures insufficient to induce instantaneous breakdown. The delayed fracture initiation process is related to the so-called static fatigue which is observed in many quasi-brittle materials, including rocks, as a collapse which is delayed in time but will occur even if the applied stress is below the material strength. Our experimental results show that this time delay can be influenced by various factors, such as the fluid viscosity and acidity, and the confining stresses. Practically this means that fracturing fluid can be chosen to enable the initiation and growth of hydraulic fractures under conditions where the required wellbore pressure for instantaneous initiation cannot be reached. Numerical model accounting for the subcritical fracture growth - captured the experimental observations of the delayed initiation. The modeling also supported the delayed initiation mechanism to allow for a greater proportion of the clusters to be stimulated via the initiation of additional hydraulic fractures within the stage when the wellbore pressure starts to plateau or decline following the initiation of the first fracture.

Selected References

Charles, R.J., 1958, Static Fatigue of Glass. II: Journal of Applied Physics, v. 29/11, p. 1554-1560. DOI.10.1063/1.1722991

Fernau, H.C., G. Lu, A.P. Bunger, R. Prioul, and G. Aidagulov, 2016, Load-Rate Dependence of Rock Tensile Strength Testing: Experimental Evidence and Implications of Kinetic Fracture Theory: Proceedings 50th US Rock Mechanics/Geomechanics Symposium held in Houston, Texas, USA, 26-29 June 2016, Paper ARMA-2016-369, 7 p.

Lu, G., E. Gordeliy, R. Prioul, G. Aidagulov, and A.P. Bunger, 2018, Modeling Simultaneous Initiation and Propagation of Multiple Hydraulic Fractures Under Subcritical Conditions: Computers and Geotechnics, v. 104, p. 196-206. DOI.org/10.1016/j.compgeo.2018.08.008

Lu, G., E.C. Uwaifo, B.C. Ames, A. Ufondu, A.P. Bunger, R. Prioul, and G. Aidagulov, 2015, Experimental Demonstration of Delayed Initiation of Hydraulic Fractures below Breakdown Pressure in Granite: paper ARMA-2015-190 presented at the Proceedings 49th US Rock Mechanics/Geomechanics Symposium, San Francisco, CA, USA, 28 June- 1 July 2015, Paper ARMA-2015-190.

Lu, Q., G. Lu, R. Prioul, G. Aidagulov, and A.P. Bunger, 2018, Impact of Fluid Acidity on the Time-Dependent Initiation of Hydraulic Fractures in Carbonate Rocks: Rock Mechanics and Rock Engineering, v. 51/12, p. 3895-3906. DOI.org.10.1007/s00603-018-1544-8

Lu, Q., G. Lu, A.P. Bunger, R. Prioul, and G. Aidagulov, 2017, Impact of Fluid Acidity on the Time-Dependent Initiation of Hydraulic Fractures in Carbonate Rocks: Proceedings 2017 ARMA 51st U.S. Rock Mechanics/Geomechanics Symposium, 25-28 June, San Francisco, California, USA, Paper ARMA-2017-200.

Winner, R.A., G. Lu, R. Prioul, G. Aidagulov, and A.P. Bunger, 2018, Acoustic Emission and Kinetic Fracture Theory for Time-dependent Breakage of Granite: Engineering Fracture Mechanics, v. 199, p. 101-113. DOI.org/10.1016/j.engfracmech.2018.05.004

Zhurkov, S.N., 1984, Kinetic Concept of the Strength of Solids: International Journal of Fracture, 26/4: 295-307. DOI.org/10.1007/BF00962961

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Common challenges in MSF Stimulation of Unconventional reservoirs in the Gulf Region
- Active tectonics: hostile stress regimes with large and varied stresses
- Deep, very competent and heterogenous rocks
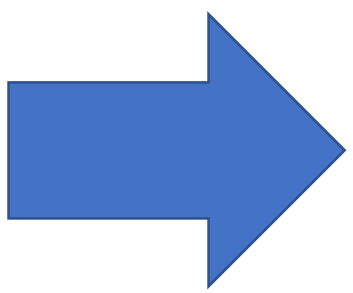
**Significant percentage of stages are failed or canceled**
- Inability to break the rock down within the pressure limits of pumps and completion
- Within fractured stages there are clusters that do not contribute to production

Are there alternative fracturing mechanisms which can improve the ratio of successful stages?

Delayed fracture initiation, also known as *static fatigue*:
- Failure of the materials under loads that are *insufficient* to cause instantaneous breakage
- Observed in many materials, including, rocks but ignored in the current HF design models based on LEFM

Simple Experimental evidence: Bending Tests on Granite beam samples
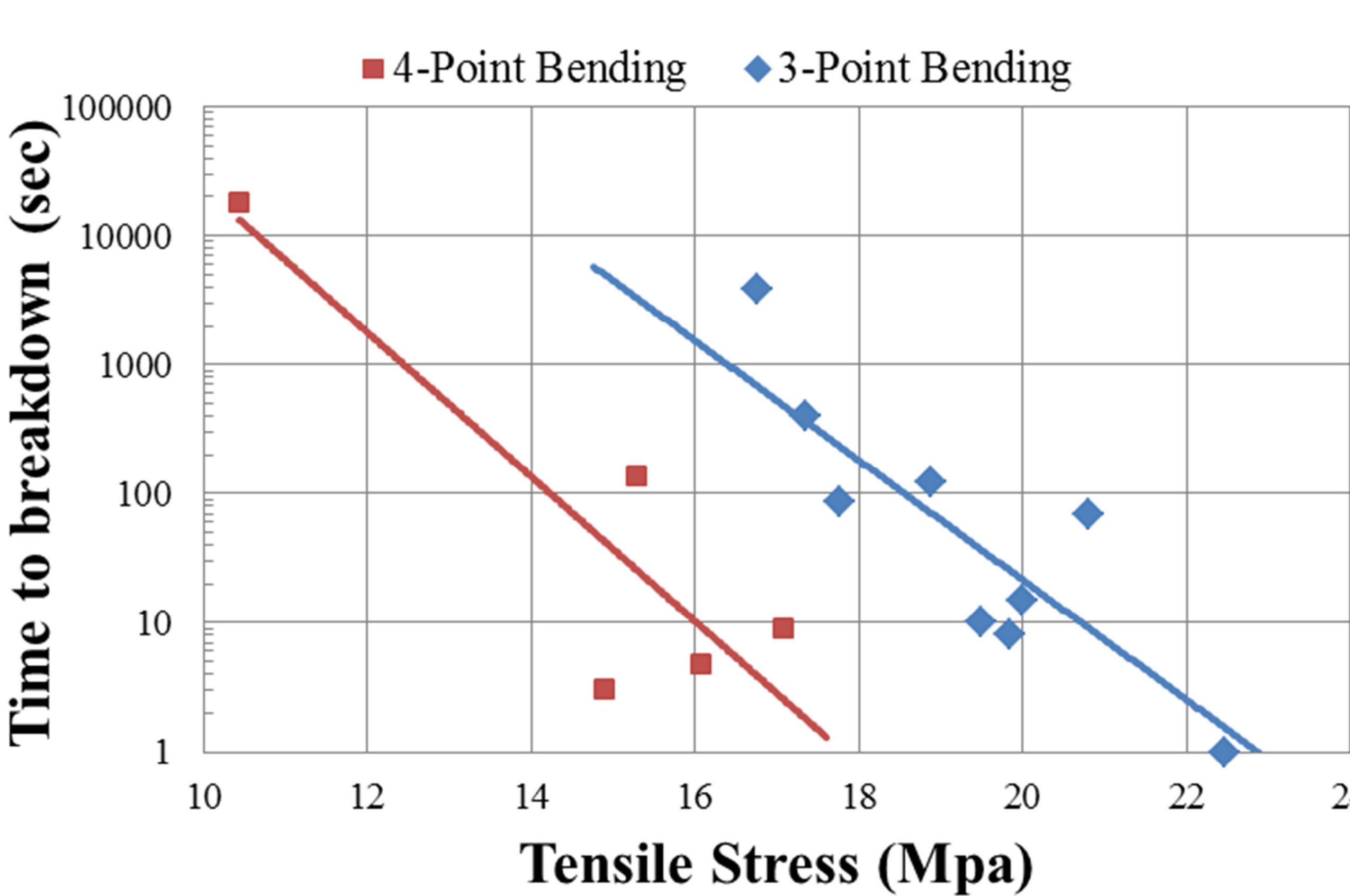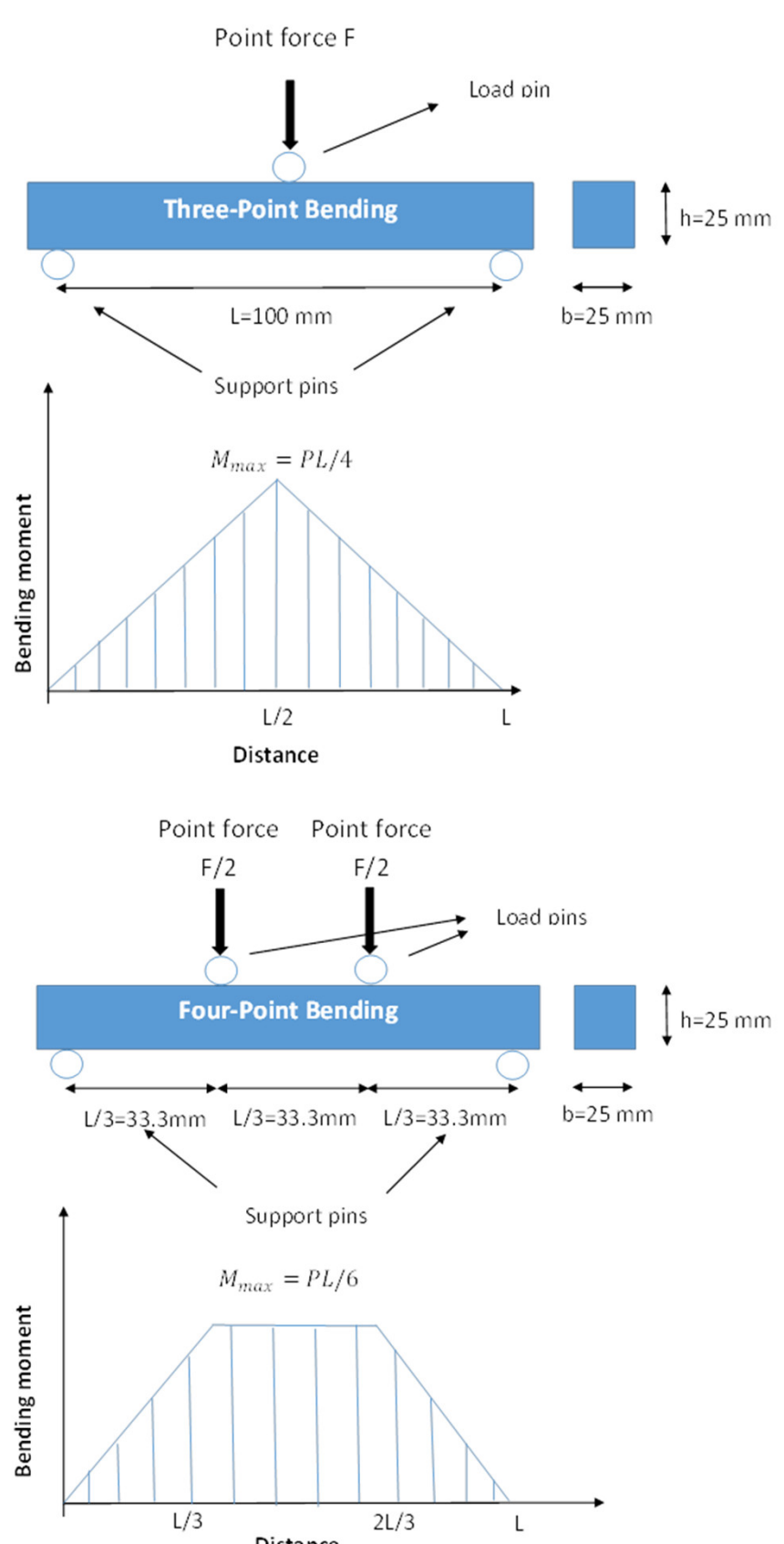
$$\sigma_T(t_1) = (1 - \chi(t_0, t_1))\sigma_T(t_0)$$

- Time to failure is best fitted by exponential law according to Zhurkov (1984) kinetic fracture theory

- In both loading configurations, apparent strength decreases by 40% after 10,000 sec of loading
$$\chi^{3P}(1,10000) = 0.38$$
$$\chi^{4P}(1,10000) = 0.40$$

Can similar time-dependent failure be found in pressurized wellbore during hydraulic fracturing?

Numerical model

$$V = A\left(\frac{K_I}{K_{IC}}\right)^n$$

- 2D (plane strain or axisymmetric)
- Single or Multiple hydraulic fractures
- Impermeable, linear elastic rock (E, ν, K_{IC})
- Fully-coupled with flow of viscous frac fluid
- Empirical law of subcritical crack growth when $K_I < K_{IC}$ with V – fracture tip velocity; n – subcritical crack growth index (Charles, 1958).
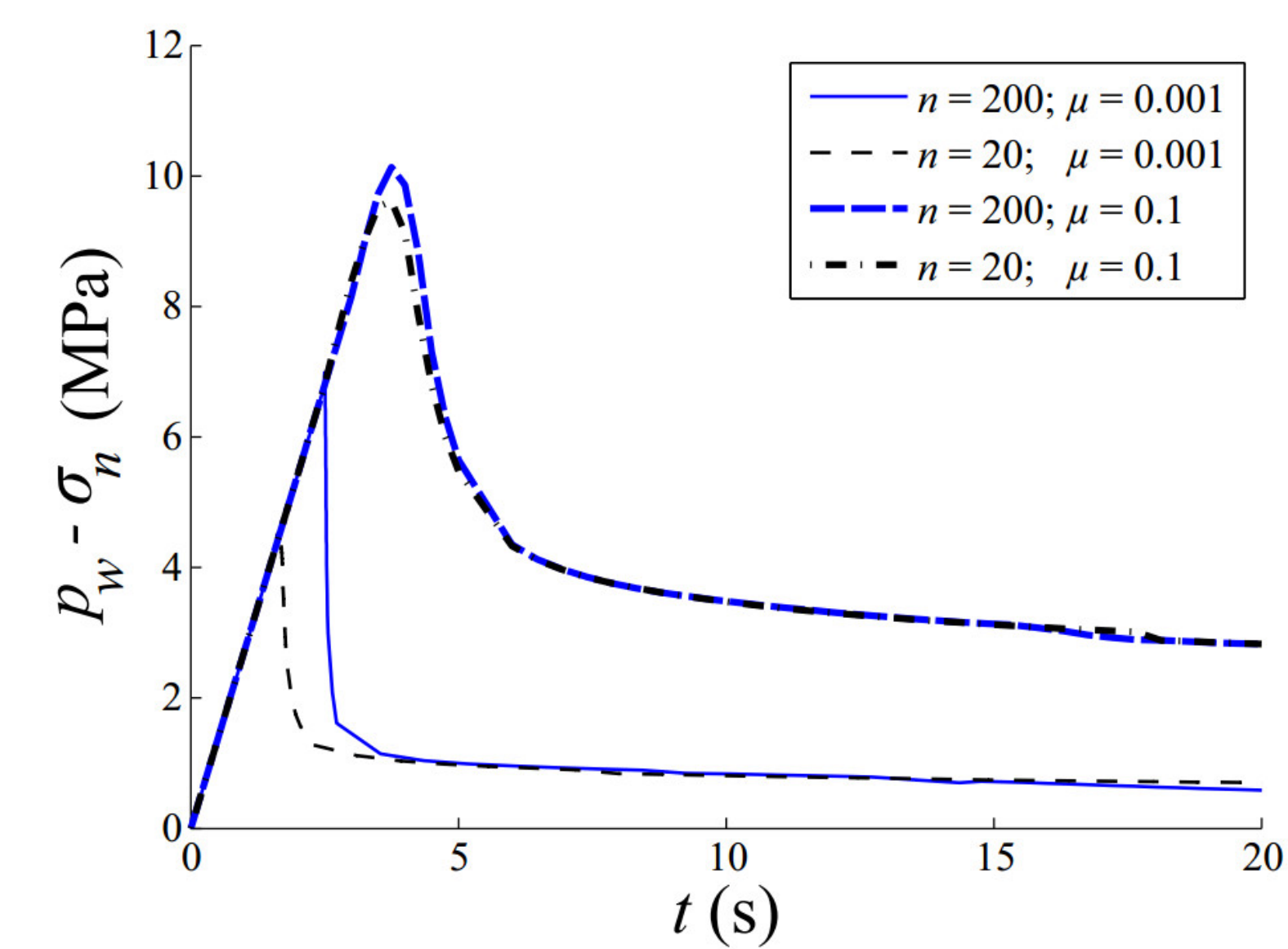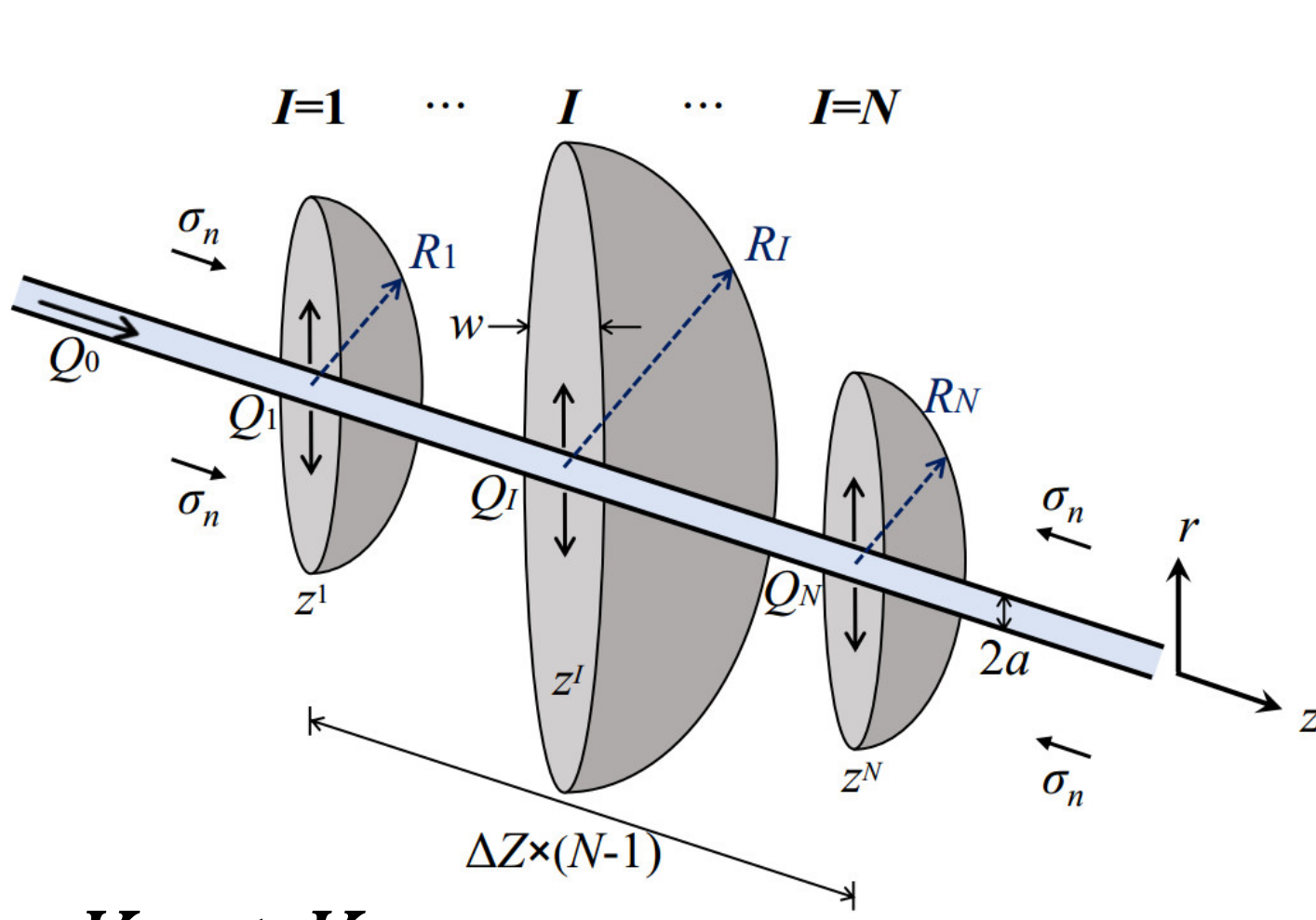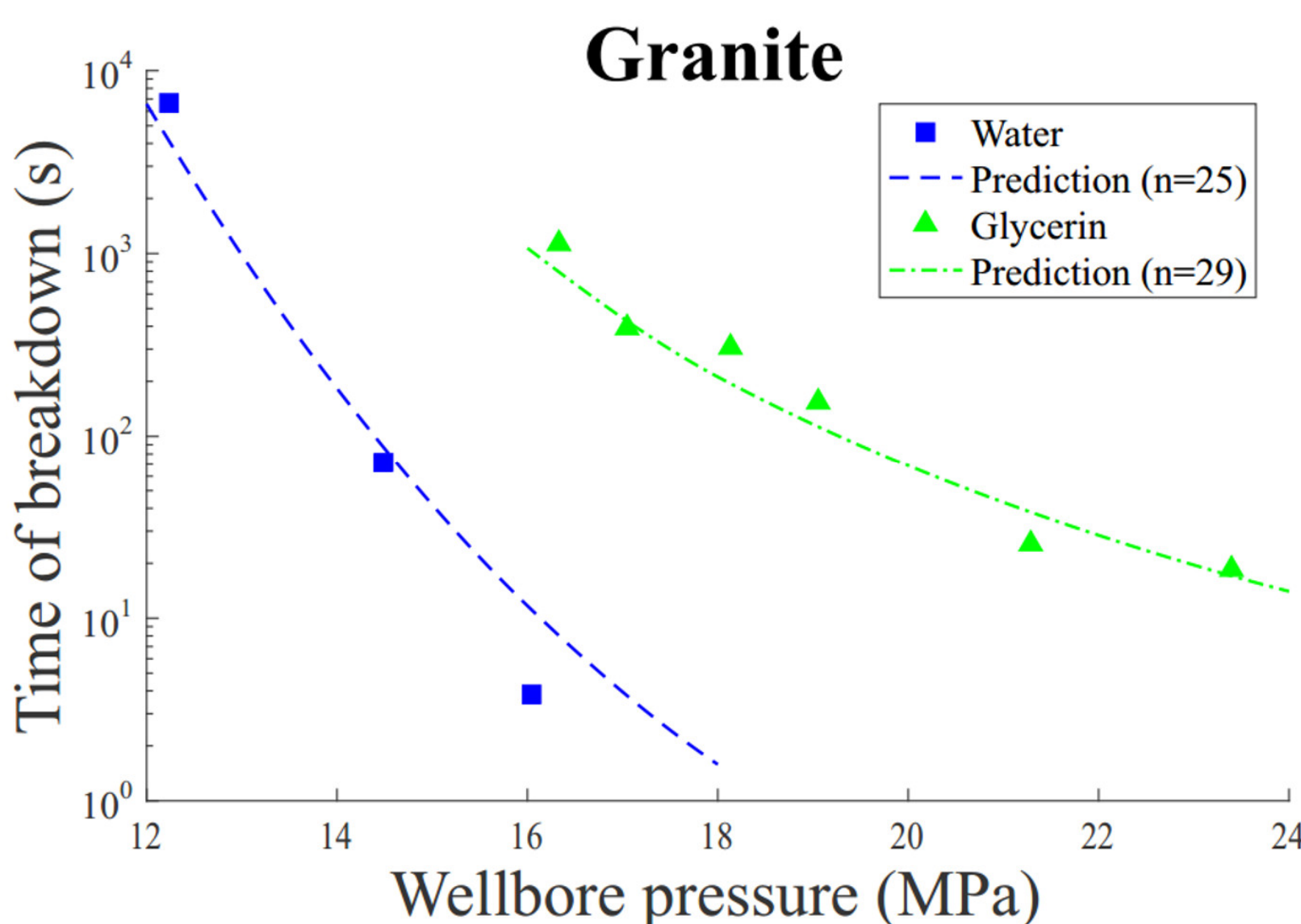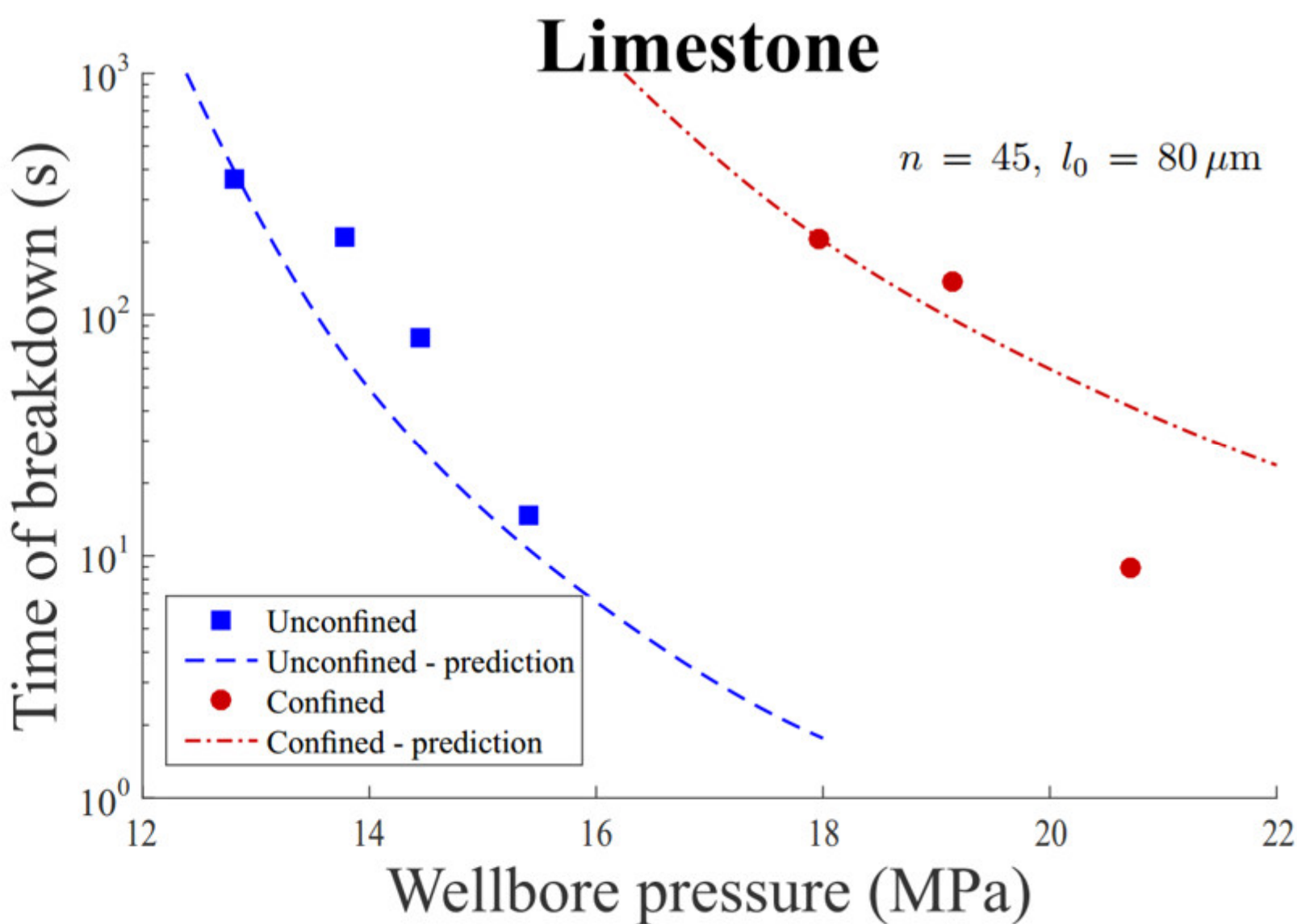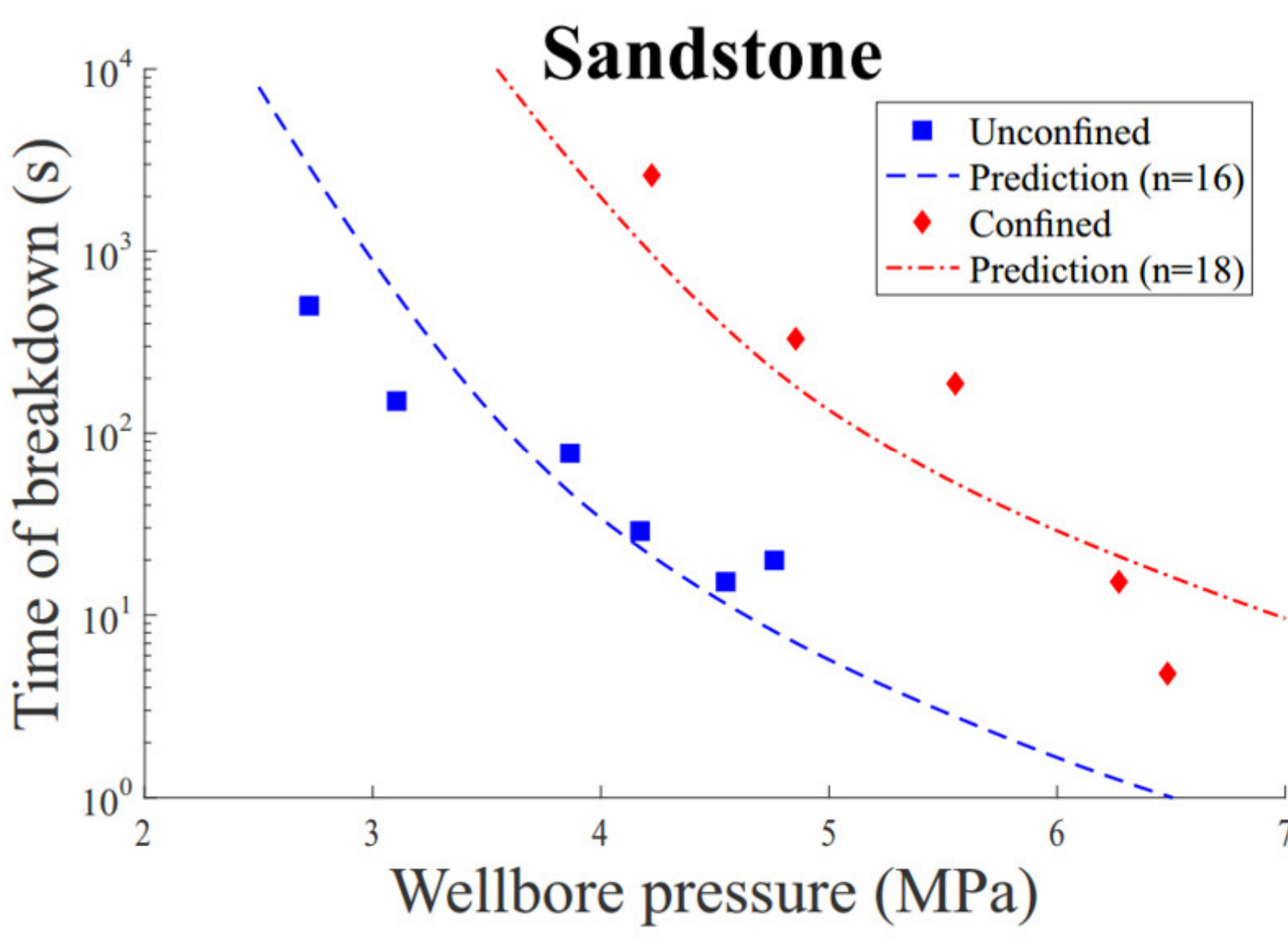

Delayed Initiation of Hydraulic Fracture in the Lab
- True-triaxial load frame at University of Pittsburgh
- Samples: cubes, 150 mm side
- 12.5 mm diameter borehole
- 50-mm-long openhole section
- *3 rock types*: sandstone, limestone, granite
- *Fluids*: non-viscous, viscous, reactive
- *Applied stresses* ($\sigma_h, \sigma_H, \sigma_v$): unconfined and confined (up to 6 MPa)
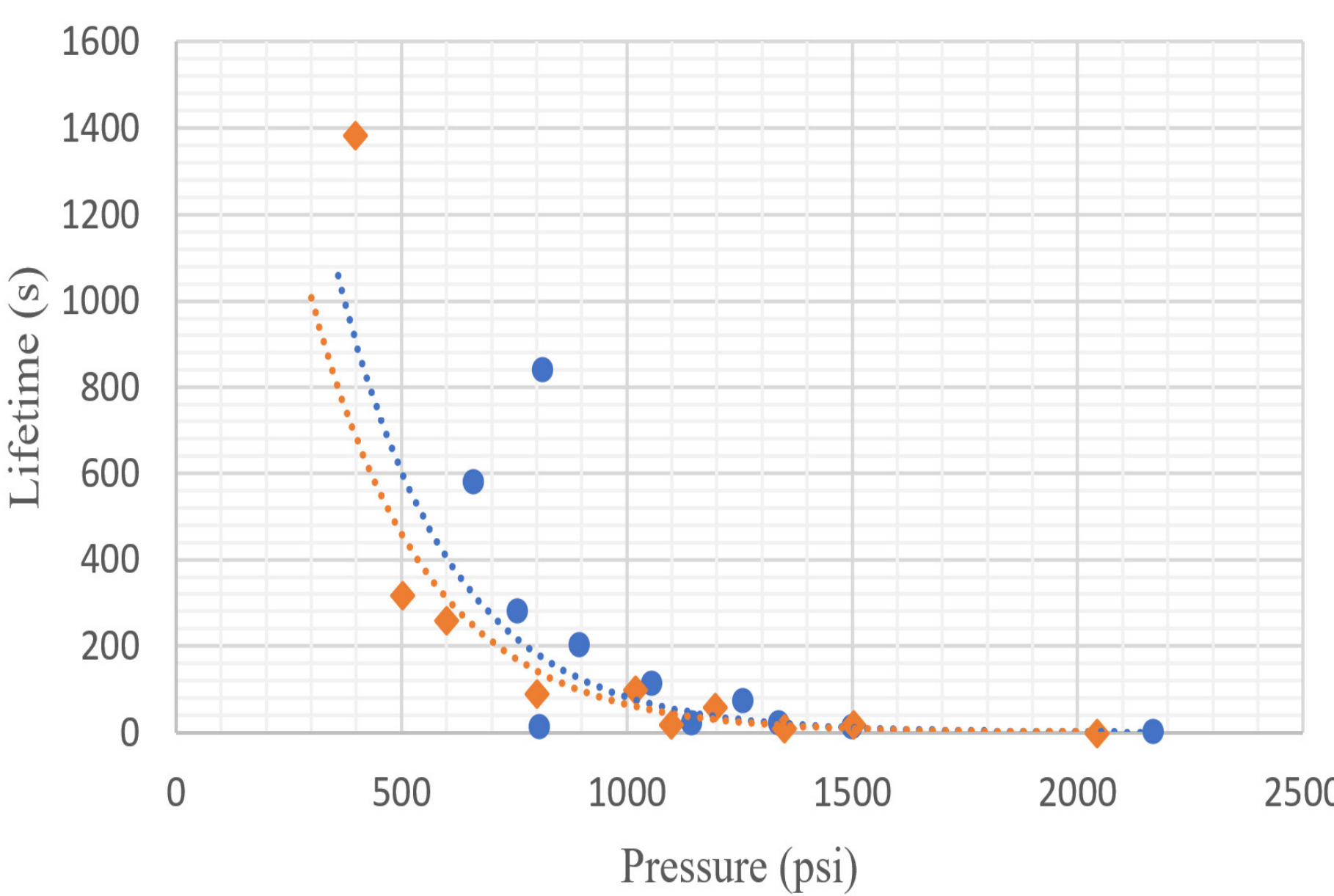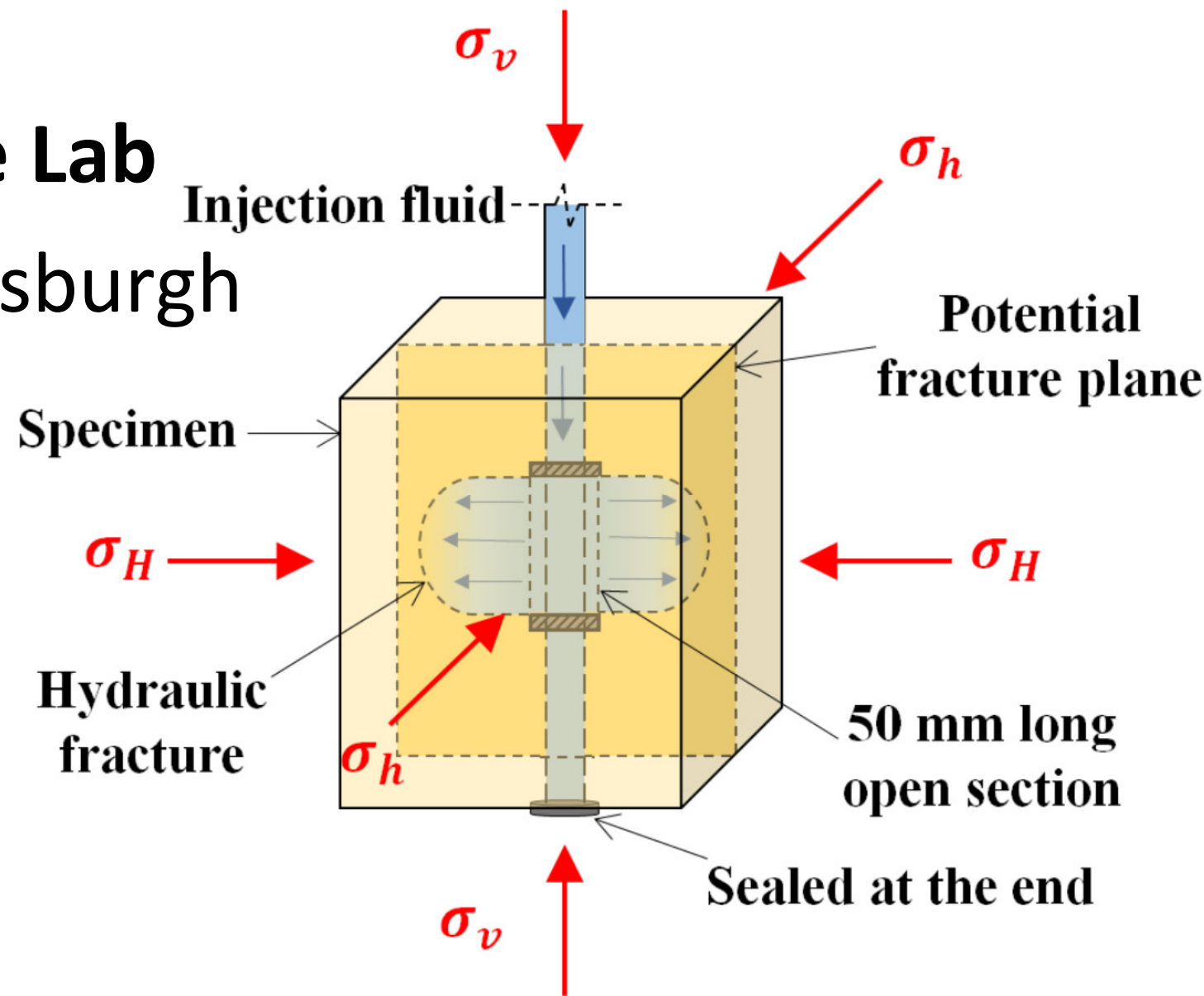

Borehole pressure is built up rapidly and held at the given target value. Time required to breakdown is measured.

Conclusions:
- Subcritical (delayed) fracture initiation may reduce breakdown pressure and completely change multiple hydraulic fracture growth compared to LEFM
- The effect is emphasized as delay time (exponent n) is decreased
- The latter can be tuned via chemo-mechanical fluid-rock interaction
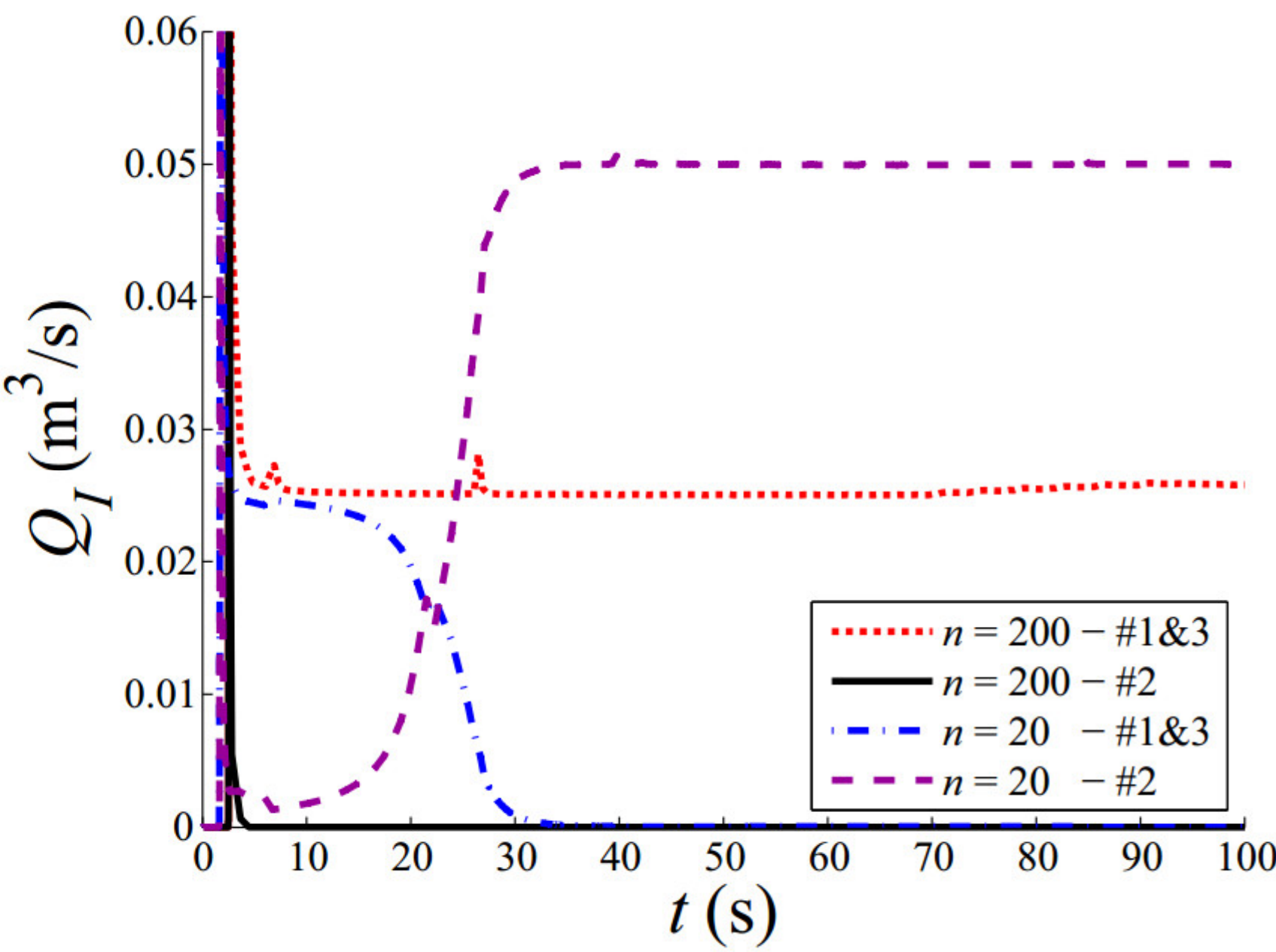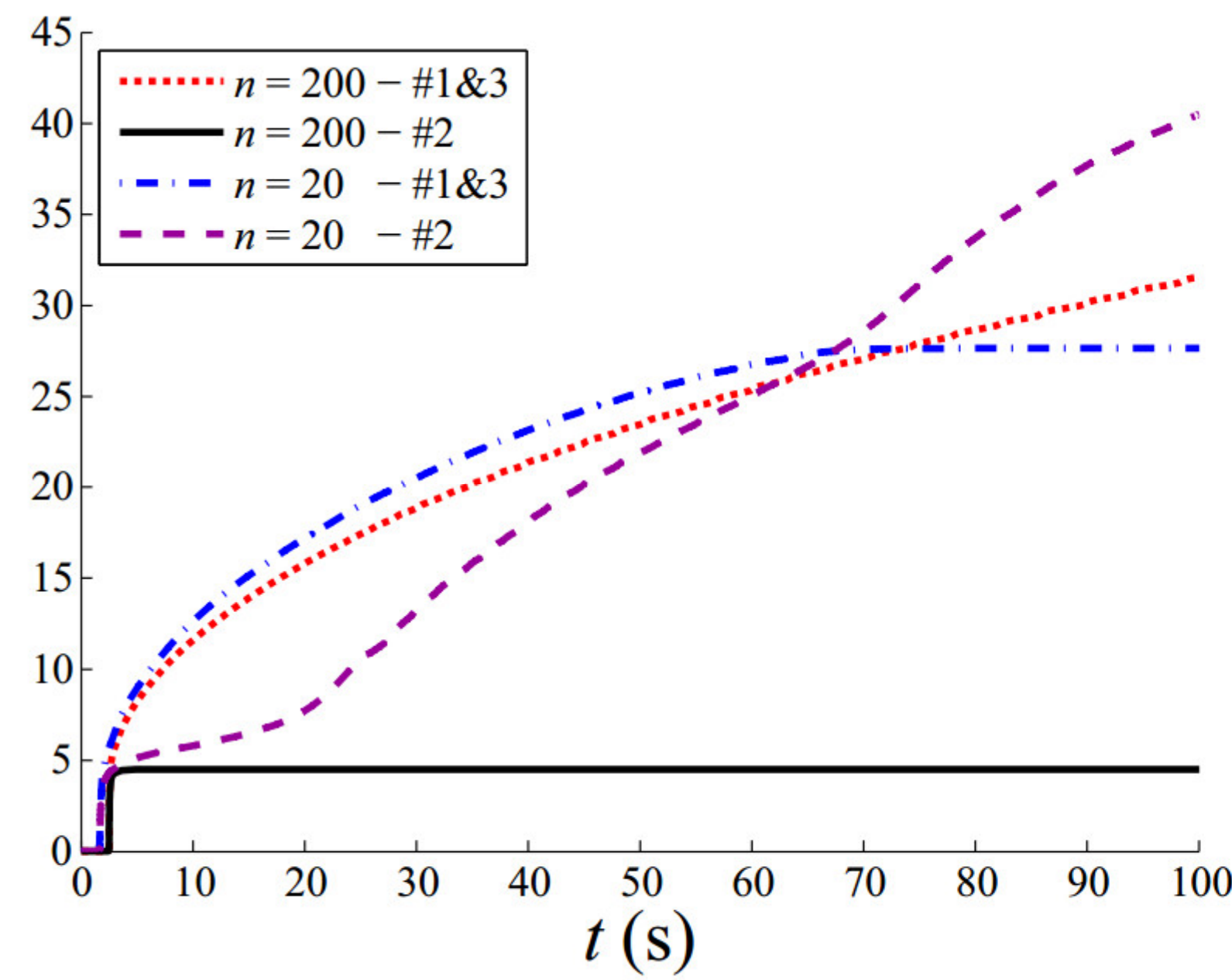
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